3. 1. 3. 2 324-MHz Klystron

Klystron Specification and Test

Since a 324-MHz klystron, of which specification is shown in Table 3.1.3.2.1, was the lowest-frequency one in practical use and is mounted horizontally, it was necessary to confirm the couples of key issues by making the model. A high-power beam test tube, mounted horizontally, and composed of a modulating-type electric gun and a collector, was manufactured first and tested to be confirmed the technical feasibility [1]. After the successful evaluation, this test beam-tube was now used as the load of the anode-modulator. In order to establish the design procedure, a high-power test model of a co-axial window was also made and tested [1]. Then the prototypes were manufactured and tested from 1999 to 2000 [2].

Table 3.1.3.2.1 Specifications of the 324-MHz klystron.

Item	Unit	Max.	Working(Sat.)	Min.
Operating frequency	MHz		324	
Peak output power	MW	3.0	2.5	
Beam pulse width	μs		700	
RF pulse width	μs		650	
Repetition Rate	pps		50	
RF Duty	%		3.25	
Beam Voltage	kV	110	102	
Beam Current	A	50	45	
Micro-perveance			1.37	
Efficiency	%		55	
Gain	dB		50	
RF window			Coaxial window	
Output waveguide			WR2300	
Mounting position			Horizontal	

This klystron had 5 cavities, and one of them was a second harmonics cavity to aim for the high efficiency. All cavities had a tuning mechanism to get the optimum performance easily in test. Co-axial window was used and the wave-guide to co-axial transition structure adopted the T-bar structure, which was changed from the door knob structure used in the window model mentioned above since the T-bar structure has a better VSWR characteristics and wider frequency band in our specified frequency range. Air cooling was employed to cool the window ceramic considering the ceramic size and coaxial structure. After the test, they are now used for high-power tests of the waveguide components and accelerator structure in a new klystron gallery in KEK. FIG 3.1.3.2.1 shows the test facility in the klystron gallery.

Prototype Test and its Results

Strong spurious oscillations were observed at the first test of the prototype klystron.

FIG 3.1.3.2.1　324-MHz klystron and waveguide system in klystron gallery.

These occurred under the high-voltage operation in the range of 65-72 kV voltage and higher than 90 kV without any drive input power. The oscillation frequency was nearly the same as the operating one. After the experimental investigations, it was cleared that the backstreaming

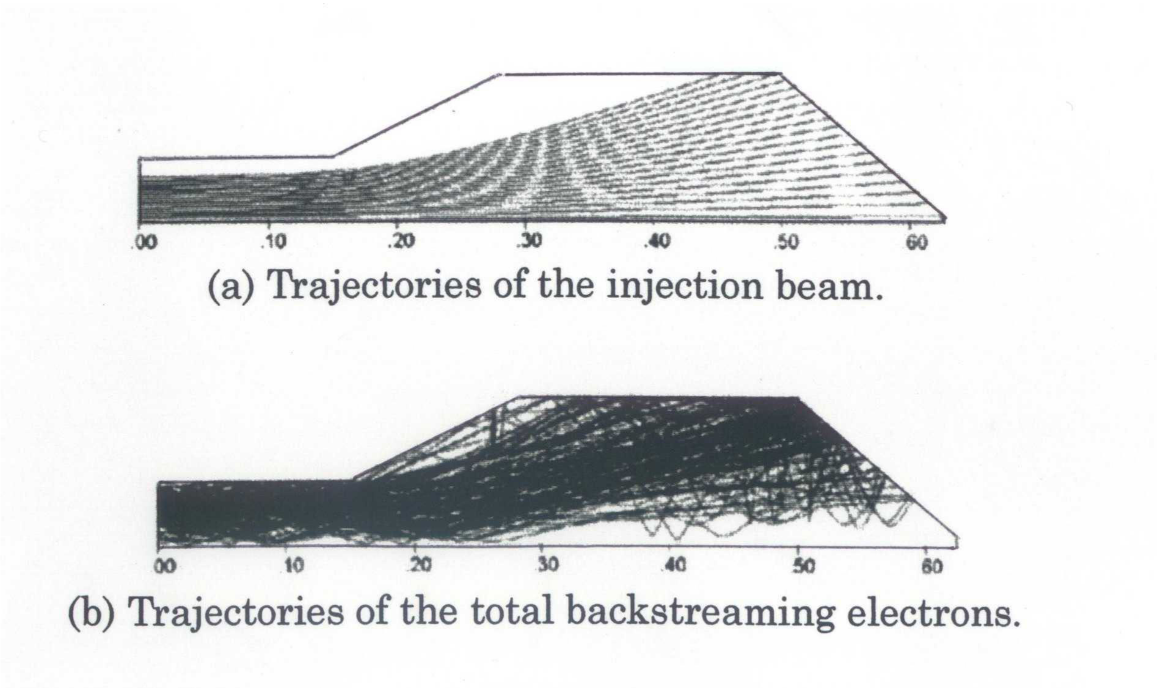

FIG 3.1.3.2.2 Trajictory of (a) primary injection beam in collector and (b) backstreaming beam scattered at the collector wall for the #1A klystron.

electrons scattered in the collector induced these strong oscillations. This was confirmed by impeding the backstreaming electrons under the weak deflecting magnetic field in the collector. This phenomenon was also analyzed by computer simulation including the effect of

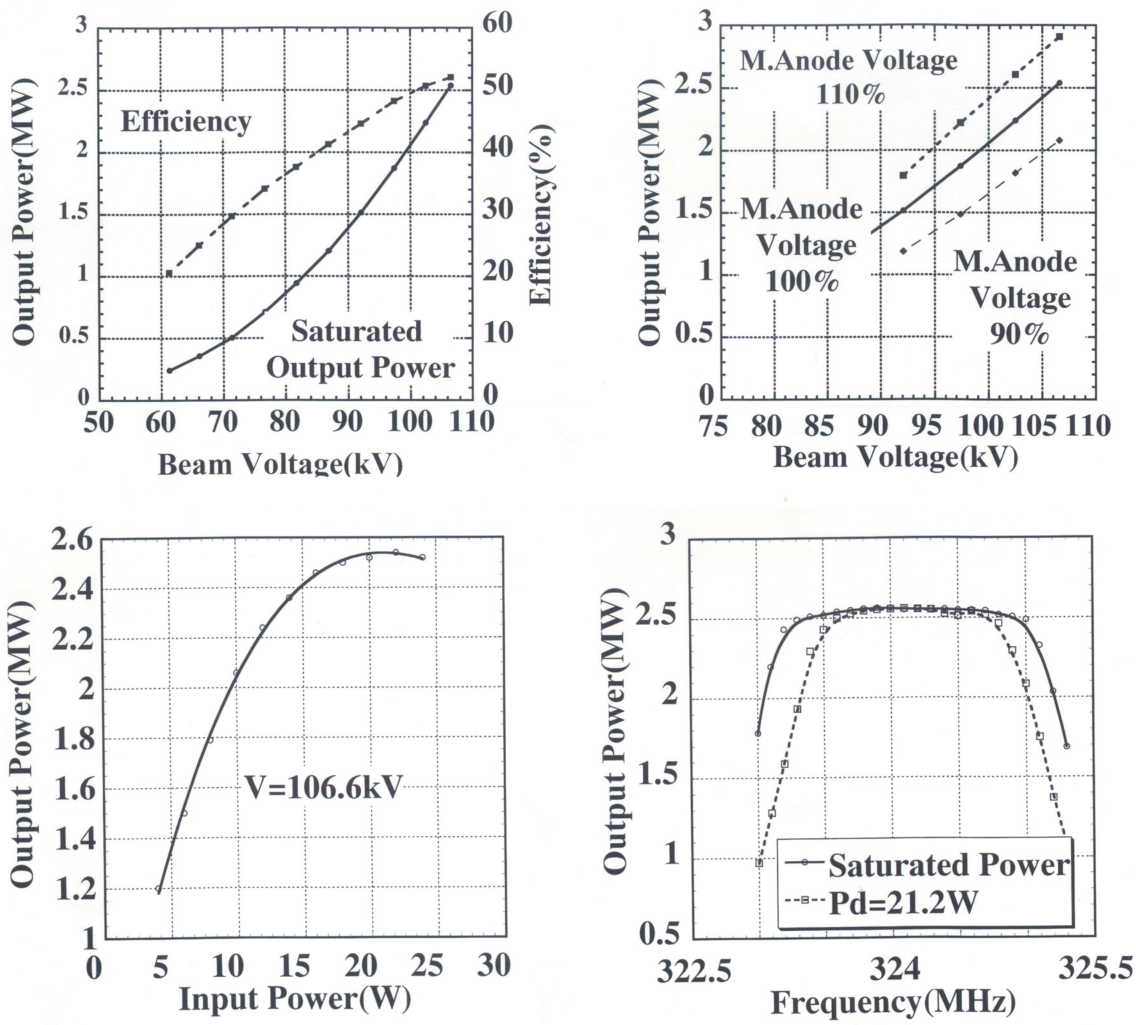

FIG 3.1.3.2.3 Performances of the prototype klystron #2.

scattered electrons at the collector wall, calculated using EGS4 code [3]. Then it was cleared that this phenomena was the same ones which were widely observed in TWT and magnetron devices [4]. At the prototype klystron design, the diameter of the tube determined by the frequency-scaling low was larger than the cathode diameter, so the drift tube diameter near to the cathode was chosen to be smaller than it and then the diameter was expanded to it in order to reduce the focus magnetic field strength. The amount of backstreaming electrons was shown to be determined by the aspect ratio of the drift-tube diameter to the collector-diameter. Detail analysis showed that smaller was this aspect ratio, larger were the number of the backstreaming electrons. In FIG 3.1.3.2.2, the trajectory examples of the prime beam and the backstreaming electrons in the collector region are shown. From a simulation using the EGS4

Table 3.1.3.2.2 Collector shapes and experiment results for the oscillation threshold beam voltage.

Tube	Collector radius (cm)	Collector length (cm)	Oscillation threshold beam voltage (kV)
#1	6.5	62.4	63<V<71, 90<V
#1A	11.5	92.4	95<V
#2	11.5	122.4	104<V or no-oscillations up to 110kV

code, it became clear that the backstreaming electrons could be decreased by using a larger-diameter collector or a smaller drift-tube diameter [5]. Several experiments using the klystrons with different collector shapes were performed to eliminate these oscillations and the associated unstable phenomena related with an input drive power. The test results changing the collector diameter are summarized in the Table 3.1.3.2.2, and the clear improvements were obtained by these changes of the collector size. Finally we had obtained the performance as shown in FIG 3.1.3.2.3. Nearly 3-MW output power and the efficiency of 52% were obtained when the anode voltage was applied at a value 10 % higher than the nominal dividing ratio between the cathode and modulating anode voltage for a cathode voltage of 105.6kV. These proto-type klystrons are now used for high-power tests of the waveguide components and accelerator structure in a new klystron gallery in KEK.

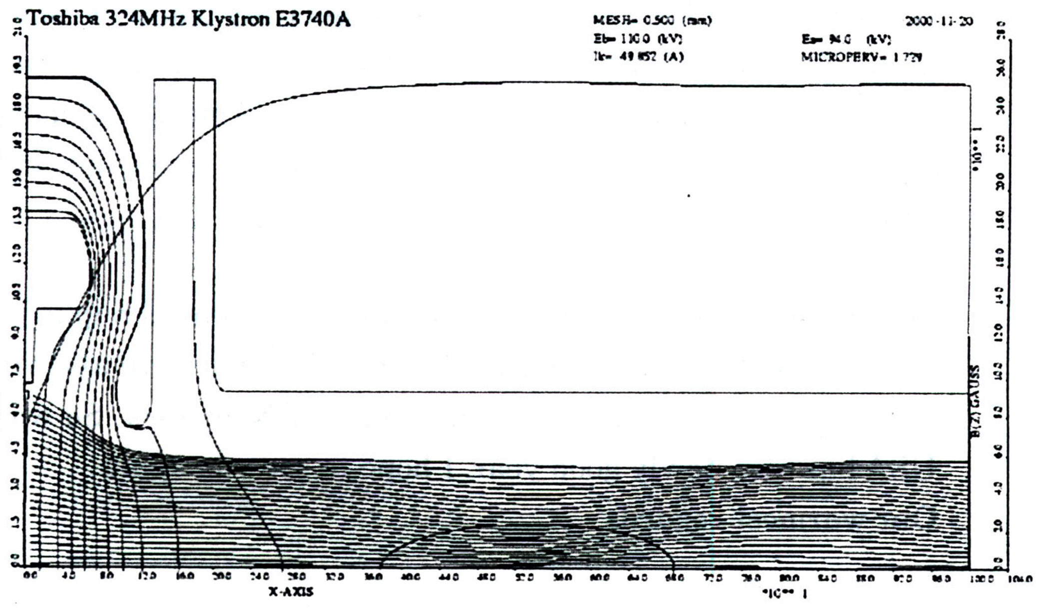

FIG 3.1.3.2.4 Beam trajectories in the gun region of newly developed klystron.

Performance of the Improved Klystron

In order to aim for a more stable operation, the new designed klystron, based on the more simple structure with the constant drift-tube diameter, was developed at Toshiba Corporation. In this design, the aspect ratio of the drift-tube diameter to the collector-diameter is chosen to be larger than the one in the prototype klystrons. In order to achieve this design, the whole focusing magnetic field strength was increased from 200 to 350 gauss. Example of showed the evidences that the stray electrons caused the instability at the intermediate the modulating anode gun design [6] calculated using the EGUN code [7] is shown in FIG 3.1.3.2.4.

This new tube was manufactured and tested in 2001. Though any spurious oscillation was not observed in this new tube performance, the slight instability was observed in the relation between the input and output characteristics. Since this was thought to be undesirable when we perform the amplitude and phase feedback control, an intense investigation was conducted. This instability involved the very high frequency components of around 1500 MHz. Further experimental investigation, by changing the focusing field and the tuning of each cavity, klystron cavity region. By choosing the proper magnetic field at the region, we succeeded in suppressing this instability. Partly this instability may related to the high gain characteristics of about 60 dB since the first cavity Q value was chosen to be larger than before. It was also necessary to change the related intermediate cavity design. The final tube has an improved design and tuning for the intermediate cavity. A maximum output power of 3.04 MW was achieved at a cathode voltage of 110 kV, and an anode voltage of 95.8 kV, which corresponded to the same condition as the proto-type. Practical operation outputting 2.5-MW power, which requires two focusing coil power supplies and the standard setting of the modulating-anode and cathode voltages giving the specified beam perveance, was achieved at a beam voltage of about 104 kV and an efficiency of about 56%. These data are

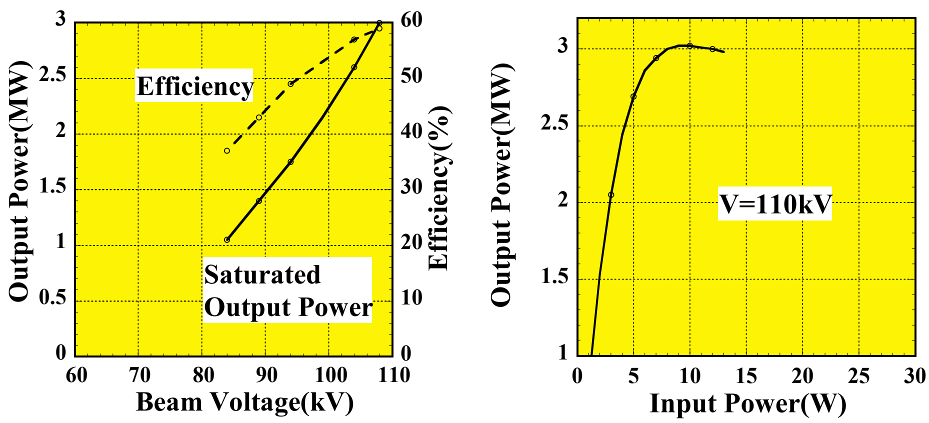

Figure 3.1.3.2.5 Characteristics of the newly developed klystron.

shown in FIG 3.1.3.2.5 and the waveforms are shown in FIG 3.1.3.2.6. Since in this operation mode, the working point is chosen to be in a region of 10-20% lower than the saturation level in the range of the input driving power, this obtained result was satisfactory. We had tested 7 klystrons, and so far had no serious troubles, such as arcing, which the crowbar circuit started to act on. During high-power evaluation tests, troubles with the dummy load were experienced at a 3-MW output power with a 620-μsec pulse width and a 50-pps repetition rate. It was thus necessary to improve the high-power coaxial dummy load. The klystron window's performance was operated without any serious troubles. The original design adopted forced air-cooling to the window. We recently changed it to water-cooling after considering the maintenance. From a practical usage point of view, it was necessary to reinforce the X-ray shield of the klystron, though it is equipped with a lead shield at the region from the gun to the drift-tube and the collector region. Measuring the X-rays from the klystron at the full rating was performed and used to develop a compact X-ray shield. An additional shield was set in the region from the penultimate cavity to the output cavity. Therefore, a complete full model suitable for installing in the klystron gallery of the 200-MeV proton linac was established. In FY2002 we had ordered the required numbers of 324-MHz klystron to the

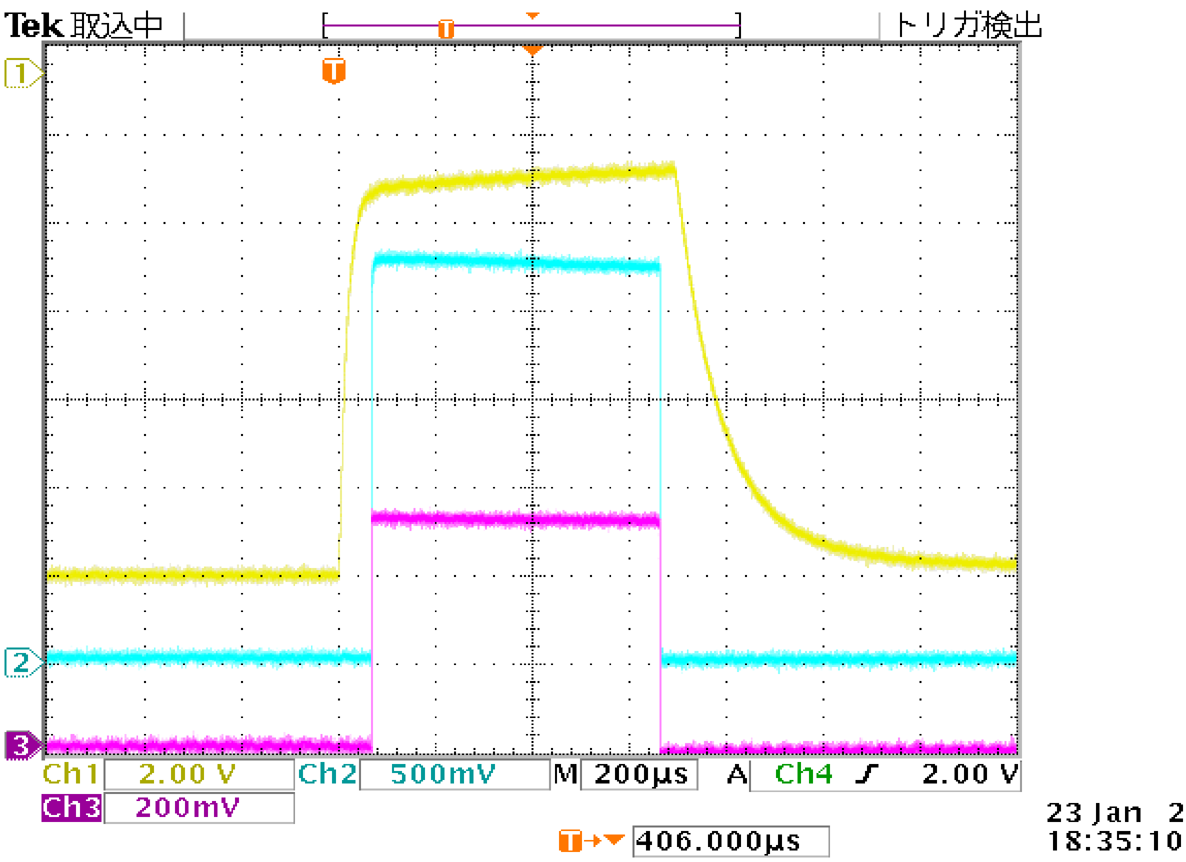

FIG 3.1.3.2.6 Waveforms of pulsed current from the cathode (top), output RF power (middle) and input RF power (bottom). One division for the horizontal scale is 200 μs.

klystron vendor in accordance with these final tube version. Recent development was reported in reference [8].

An rf feedback study and high-power component tests given in reference [9] were performed using this klystron in the gallery. High-power tests of the RFQ, DTL and SDLT structures were also performed using these 324-MHz klystrons.

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